Photon Path Density Strongly Correlates with Photon Intensity in Self-Interference

by

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Summary. A quantitative estimate is given for the goodness of fit between the location of peaks in density among experimentally and theoretically identified photon paths versus the peaks in fringe intensity produced by unperturbed self-interference. It establishes that the paths identified resolve the 'which way' problem in the quantum theory of interference, to within an error probability of four to five standard deviations.

Kocsis et al. (2011) succeeded in reconstructing eighty photon paths with precisely determined position in a split-beam interferometer, following a weak measurement of the momentum of single photons, in a procedure envisioned by Wiseman (2007) and pioneered by Aharanov, Albert, and Vaidman (1988). As the photon paths were observed to cluster into an interference-like pattern, this development offered the prospect of a compelling insight into the long-standing 'which-way path of flight' quandary (Feynman, 1989). More generally, it supported a DeBroglie-Bohm interpretation of light interference and other quantum phenomena.

In this connection, Davidovic et al. (2013) recently calculated thirty-six Bohmian trajectories, predicted to occur within the interferometer assembled by Kocsis and coworkers. Analogous to the experimental set of paths, these trajectories also clustered in a manner consistent with interference. In the absence of a quantitative estimate of path goodness of fit with perturbation-free photon interference, by either group, the relevance of each set still require substantiation. The present communication addresses this deficiency. Indeed, it shall be demonstrate that the density of reconstructed and Bohmian path clusters correlate strongly with photon intensity peaks produced through self-interference. This finding thereby validates the physical significance previously attributed to both experimental and theoretical sets of photon paths. Additionally, it directly counters an assertion by Coffey and Wyatt (2011) that the report of Kocsis et al. (2011) "shows a surprising low number of photon trajectories in regions of high probability."

Pearson product-moment correlation coefficients in excess of 0.99 characterize the correspondence observed between the distance of peaks in photon intensity and path density, measured from the optical center of self-interference patterns (see Figure). Path density is specified as the reciprocal distance between adjacent paths. From Student t-

values produced by the goodness of fit between peak locations in unperturbed interference among single photons versus their experimentally or

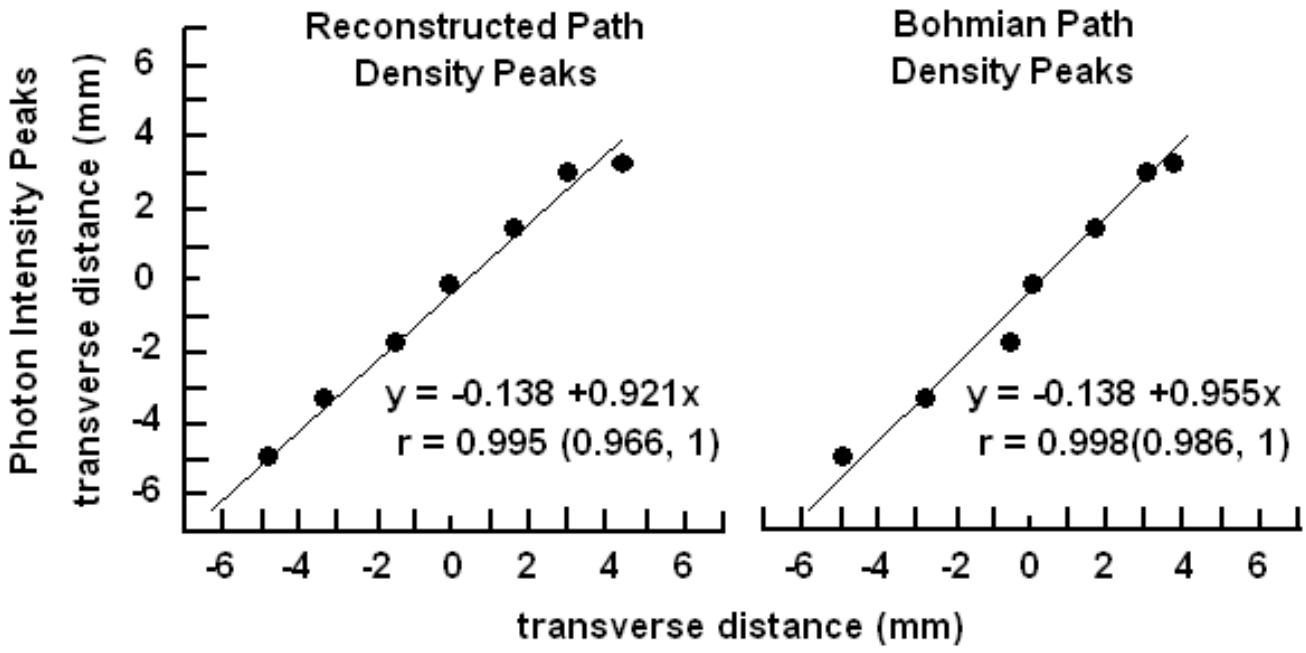

Figure. Correlation between the location of peaks in photon intensity, formed on self-interference, with peaks in cluster-density among photon paths reconstructed by Kocsis et al. (2011), averaging over weak measurements of momentum, or calculated by Davidovic (2013), using Bohmian mechanics. Intensity and cluster-density peaks were distributed, at indicated distances from the optical center, on the axis transverse to the direction of flight, at a distance of 7.7 m from the light source. They can be seen to correspond closely, having Pearson correlation coefficients, r, in excess of 0.99. Coefficient 95 per cent confidence intervals appear in parenthesis. Variables x and y, in each linear equation, respectively denote peak distance for path density and photon intensity.

theoretically obtained trajectories, the probability that each correlation could arise by chance would necessitate a four-to-five standard deviations event: *p*(Photon Intensity v. Reconstructed Path Density) = 2.92x10-6, and *p*(Photon Intensity v. Bohmian Path Density) = 4.52×10^{-7} with t values of 22.957 and 33.411, at 5 degrees of freedom, respectively. Numerical values for the distances on which these calculations are based appear in an attached table (see Attachment) and they represent a weighted average across each peak.

The result presented provides the strongest known quantitative confirmation that the photon paths reconstructed by Kocsis et al. (2011) and deduced by Davidovic et al. (2013) have resolved the 'which way' problem (Feynman, 1989) in the quantum mechanics of light interference.

References

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Attachment

Table Location of fringe peaks in photon intensity at 7.7 m from a source within a split-beam interferometer versus density peaks in reconstructed and Bohmian path clusters.[1]

Fringe Intensity	Path Density	
	Reconstructed	Bohmian
	peak distance from optical center (mm)	
-4.803	-4.951	-4.988
-3.178	-3.256	-2.909
-1.600	-1.498	-1.546
-0.040	-0.022	-0.040
1.527	1.492	1.605
3.047	3.0	
3.307	4.329	3.930

[1]Peak distances used to calculate correlations obtained.